FURY: A REMOTE UNDERGROUND STORAGE TANK INSPECTION AND ASSESSMENT SYSTEM

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EXECUTIVE SUMMARY

Nationwide it is estimated that there are over 300,000 metallic Underground Storage Tanks (USTs). Near the end of 1998, Federal regulations (40 CFR 280) will require that all of these tanks be brought into regulatory compliance to avoid environmental contamination. Replacing all existing USTs would be prohibitively expensive. One allowed alternative is to retrofit existing USTs with cathodic protection for continued use. However, there is need for more cost-effective and reliable condition assessment methods for USTs in order to support better informed management decisions.

To meet this need a remote robotic UST condition inspection/assessment system named “Fury” is being developed and is currently undergoing field testing and validation. Fury enters the UST through an existing riser (4-inch diameter minimum) or manway and navigates using magnetically coupled wheels to access virtually all of the end cap and cylindrical wall area. A sensor sled takes multiple (approximately 90,000 per hour) ultrasonic thickness measurements while in motion and relays the readings along with position information to a computer. In its final form Fury is intended for immersion into fuel while filling the head space with a protective blanket of inert gas, thus allowing no interruption of normal operations.

In addition to providing a non-destructive evaluation tool which offers considerably more pertinent quantitative data compared to existing assessment technologies, a Fury UST inspection will also be significantly faster. An equally important benefit is the avoidance of the expense and danger associated with confined space entry.

Fury is being developed by the U.S. Army Construction Engineering Research Laboratories (USACERL) in conjunction with RedZone Robotics, Inc., of Pittsburgh, PA. The effort is being funded by the Small Business Innovation Research Program (SBIR), the Environmental Security Technology Certification Program (ESTCP) and the Army Petroleum Center.

INTRODUCTION

According to Federal law 40 CFR 280 and 281, in order to minimize environmental contamination, all existing steel USTs must be upgraded to one of the allowed alternatives not later than 22 December 1998 [1]. In addition to removal/replacement and closure, these alternatives include the option of upgrading with cathodic protection. For USTs which are 10 years or older it is required that the tank first pass a precision tightness test to assure that there is no current leakage. Subsequently, an assessment of the tank's integrity is required prior to upgrade. Currently available methods for assessment of tank integrity are expensive, time consuming, provide a wide range of reliability, and often involve the hazard associated with confined space entry. The Fury robot, however, does not require human entry for inspection and provides many multiple direct and quantitative measurements of the single most important aspect of UST integrity—remaining wall thickness.

External pitting is by far the most prevalent form of corrosion responsible for UST perforations. One study examined 500 steel USTs immediately after excavation [2] and another analyzed test data from 1,635 steel USTs [3]. It was determined from both studies that external pitting corrosion was the cause of perforation at least 70-80% of the time. Further, internal corrosion, weld failure, or seam failure each lead to less than 10% of the perforations. With Fury's capabilities, in situ measurements are made of the wall thickness, which lend themselves immediately to statistical analysis of the tank's current condition and suitability for upgrade. Furthermore, having direct wall thickness measurements serves to improve the accuracy of existing UST life prediction models.

The Fury robotic system (Figure 1) consists of a steerable tractor with an attached measurement sled. The tractor has permanently magnetized wheels which enable the robot to adhere to the tank wall in all orientations while moving in either the forward or backward direction. Means have been provided to allow movement onto and off of the tank end caps while various bump sensors assist the operator in navigation and obstacle avoidance. The measurement sled consists of an ultrasonic thickness transducer flanked by surface preparation and cleaning devices located on both sides of the sensor. During measurements a hydraulic system is used to press the measurement sled against the tank wall while a continuous supply of ultrasonic transducer couplant is supplied. The entire robot fits through a 4-inch diameter opening and can make approximately 30 wall thickness measurements per second.

PROCEDURES AND RESULTS

In order to validate and demonstrate the capabilities of the robotic system, older USTs at both Ft. Lee, VA and Hunter Army Air Field, GA were assessed for their current condition and suitability for upgrade with cathodic protection. The Ft. Lee tank, being scheduled for removal, was used to initially test Fury. Various capabilities of the Fury system were validated. In addition to an inspection in accordance with ASTM ES40-94 [4], a number of performance capabilities were documented on videotape. This included a real time video feed from inside the tank to an outside monitor. The capabilities documented included: entry/exit through a riser pipe, adherence to the inner tank wall in all orientations, movement in the forward and reverse directions, obstacle sensing and avoidance, traversal of lap joints, transitions to and from endcap walls, navigational accuracy, surface cleaning and ultrasonic thickness measurements. After the tank was removed a third party inspection was performed by MRI, Inc. in accordance with procedures developed by the EPA [5]. The detailed and systematic inspection included a visual record, an ultrasonic thickness survey, wall thickness measurements with a through-wall micrometer, and pit depth measurements made with a pit gauge or a depth micrometer.

At Hunter Army Air Field another demonstration of the Fury robotic system was performed. Three USTs of 50,000 gal. capacity were assessed according to ASTM ES40-94. The information acquired will be used to make better informed management decisions regarding whether the tank should be upgraded or replaced. The full replacement of 30 tanks at Hunter had been estimated at $10M. If some or all of these tanks can be upgraded then a significant cost will be avoided.

A full ASTM ES40-94 assessment also includes historic information, operational procedures, and various structural corrosion potential and soil chemistry measurements. These procedures were performed in accordance with the standard. However, for the purposes of this paper only the wall thickness data obtained with the Fury robot will be addressed.

Selected Validation Results from Ft. Lee

One of the most critical comparisons was that of the Fury’s in-situ ultrasonic thickness measurements to other reference methods. Three 5x5 square grids with 10 cm. spacing were located near the center bottom, one approximately one half the distance to the end cap near the bottom, and one on one end cap. These test grids were marked out with wax pencil and stamp markers. Each measurement location was circled using a vibrating engraver and a robot template positioner. The template was used to assure that in-situ comparison measurements with a hand held ultrasonic thickness gauge were taken from exactly the same position. Both the robot sensor and the hand held thickness gauge were calibrated on the same calibration step block before and after each group of measurements. After the tank was removed the grids were cut out of the tank, sectioned, and the same measurements were performed using a standard mechanical micrometer capable of an accuracy of 1/1000 of an inch. The in-situ Fury and laboratory micrometer measurements are shown in Figures 1 through 3.

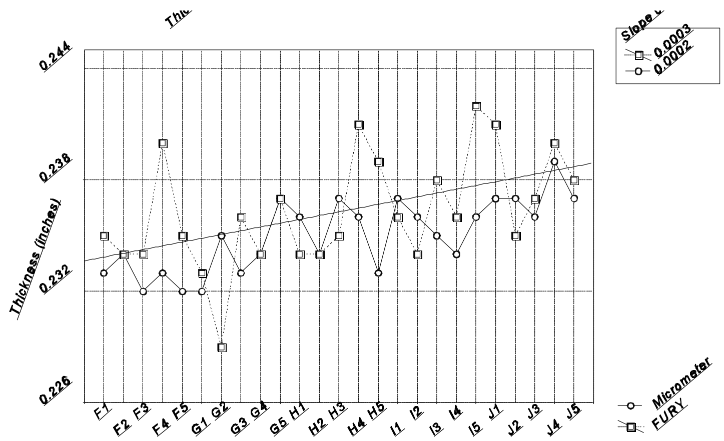

Figure 1. Bottom, Middle Mechanical vs. Fury Thickness Measurement

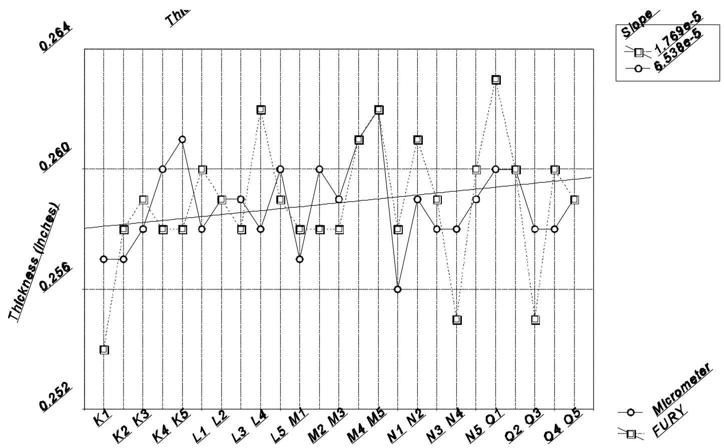

Figure 2. Bottom, Quarter Mechanical vs. Fury Thickness Measurement

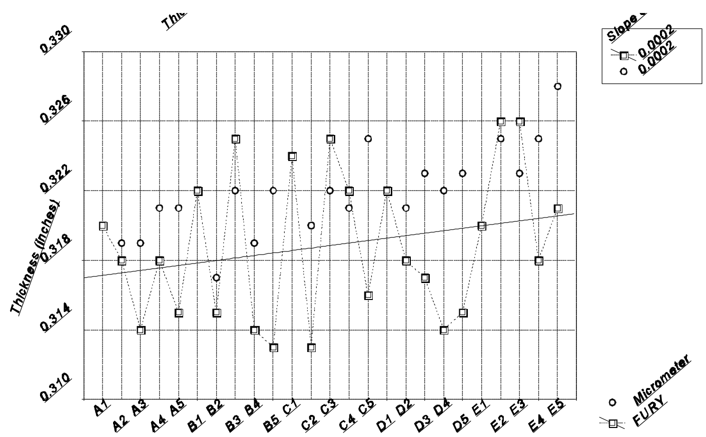

Figure 3. End Cap Mechanical vs. Fury Thickness Measurement

Laboratory analysis of the three 5x5 grid pattern readings were performed in accordance with ASTM G46 [6]. In addition, MRI, Inc. performed independent ultrasonic measurements on a different grid system in accordance with an EPA procedure for the field evaluation of USTs. The comparison of the measurements are given in Table 1. It is worth noting that the external hand-held ultrasonic measurements taken by MRI, Inc. are almost identical to those called for by the National Leak Prevention Association's (NLPA) standard 631 and, considered alone, were inadequate to determine the tank's condition. In fact, no measurement indicating a remaining wall thickness less than 50% of the original value was found.

One of the main advantages of the Fury robotic system is its ability to rapidly take data while in motion. Virtually all of the data taken at Ft. Lee was during the last day of a week-long effort after a number of other validation tasks had been completed. Table 2 shows the results of a statistical analysis for the full data set as separated into tank wall and end caps (which typically have a larger initial wall thickness). The Fury data can be displayed in a number of ways. With position coordinates associated with each measurement the positions of the thinnest measurements can be displayed. Figure 4 shows the four thinnest ranges of measurement for the curved tank wall (displayed as if viewed from above and opened to each side from a longitudinal top seam). A feature along a lower circumference, approximately eight feet from the southern end cap, is evident. This feature was visually confirmed after the tank was removed. One possible explanation is that during installation a lifting strap caused some initial coating damage which over time lead to preferential corrosive attack of that area.

Table 1. Statistical Comparison of Ft. Lee Thickness Data Sets

Method	Position	valid n	mean (in)	min(in)	max(in)	std dev(in)
Fury Robot	wall	111952	0.255	0.071	0.543	0.033
Micro-meter	wall	50	0.247	0.232	0.262	0.012
Ultra-sound*	wall	77	0.245	0.222	0.274	0.012
Fury Robot	far end cap	3683	0.324	0.251	0.485	0.0100
Fury Robot	near end cap	18	0.234	0.071	0.441	0.124
Micro-meter	end cap	20[#]	0.322	0.316	0.327	0.003
Ultra-sound*	North end cap	9	0.325	0.318	0.331	.005
Ultra-sound*	South end cap	9	0.322	0.312	0.328	0.006

*= MRI ultrasonic tank thickness measurements
# = five samples were rendered unusable by the cutting torch
n= number of data points
mean = average thickness of section
min = minimum thickness measured in section
max = maximum thickness measured in section
std. dev = standard deviation from the mean thickness

Table 2. Statistical Analysis of Complete Ft. Lee Data Set

Position	valid n	mean(in)	min(in)	max(in)	std dev(in)
wall	111952	0.2549	0.0707	0.5426	0.0333
far end cap	3683	0.3244	0.2508	0.4845	0.0100
near end cap	18	0.2336	0.0707	0.4412	0.1243

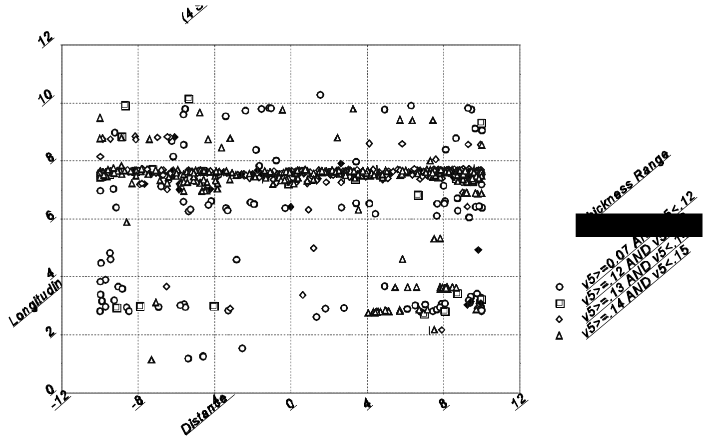

Figure 4. Location Distribution of 1000 Thinnest Wall Thickness Measurements

Validation and Results at Hunter Army Airfield

Fury collected in excess of 940,000 measurements from three USTs at Hunter Army Airfield. Each of the tanks were selected from three separate pump stations, each consisting of a bank of 10 tanks. Measurements on the bottom one-third were emphasized in order to provide a conservative assessment. Table 3 summarizes the results obtained after correction for an internal epoxy coating. The data was then sorted according to thickness. Table 4 shows the results of an analysis of the 500 thinnest measurements. Histograms showing the number of measurements within successive ranges of wall thickness are shown in Figures 5 - 10. Tanks 3 and 4 appear to be in pretty good shape while Tank 5 clearly shows a large number of observations at the lower thickness ranges. Taken together with the findings from the other procedures detailed in ASTM ES40-94 tanks 3 and 4 are considered suitable for upgrade while tank 5 is not.

From a corrosion engineering viewpoint, the character of the wall thickness histograms is intriguing. It may be that as a tank undergoes the accumulated damage of corrosive degradation, the condition represented by Figures 6 and 8 evolves more toward a condition represented by Figure 10. The statistics of these so called “extreme values” (e.g., the thinnest measurements) is currently being examined. The potential benefits include a further improvement in knowing a tank’s condition, with either an equal or lesser amount of data, as well as a greater understanding of the degradation process itself.

Table 3. Descriptive Analysis of Hunter Airfield Data Set

Tank	Valid n	mean(in)	min(in)	max(in)	std. dev(in)
3	463408	0.38945	0.07096	0.56196	0.03232
4	321919	0.37601	0.07563	0.58053	0.03305
5	157183	0.36974	0.07034	0.57284	0.06551

Table 4. 500 Thinnest Data Points at Hunter Army Airfield

Tank	mean(in)	min(in)	max(in)	std. dev(in)
3	0.12664	0.07096	0.14700	0.02270
4	0.13498	0.07563	0.14973	0.01299
5	0.07252	0.07034	0.07614	0.00164

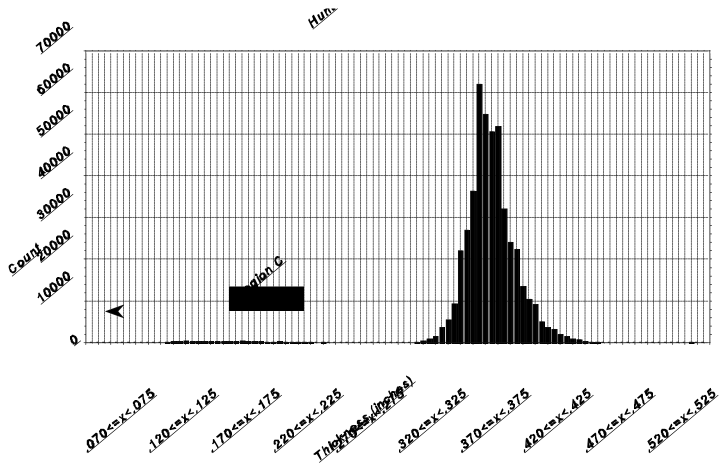

Figure 5. Thickness Distribution in Tank 3

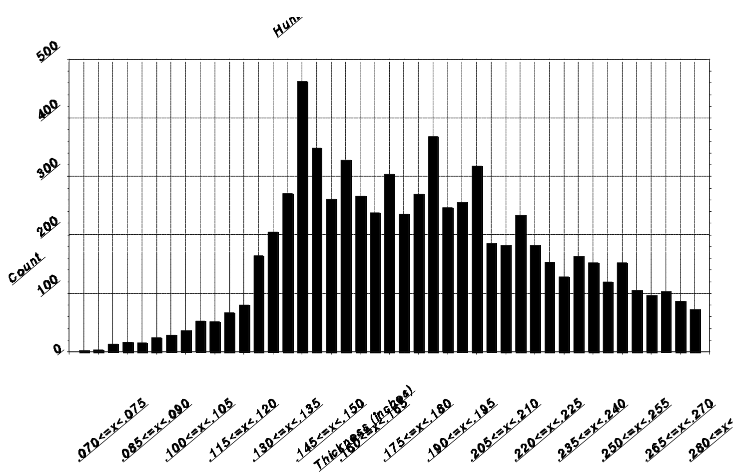

Figure 6. Thickness Distribution Region C in Tank 3 (Figure 5)

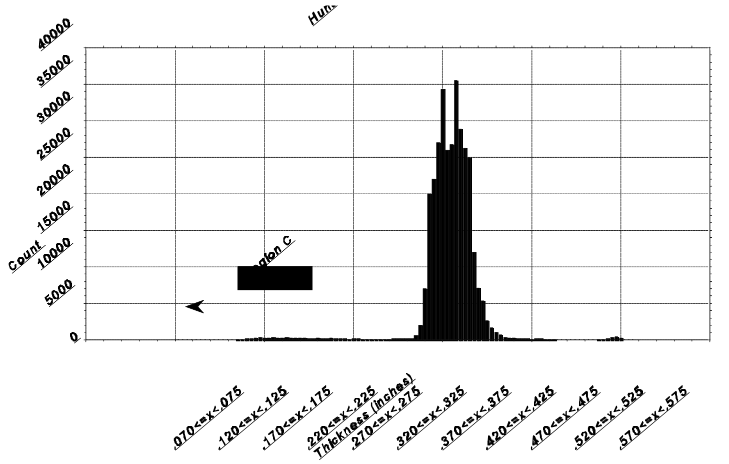

Figure 7. Tank 4 Thickness Distribution

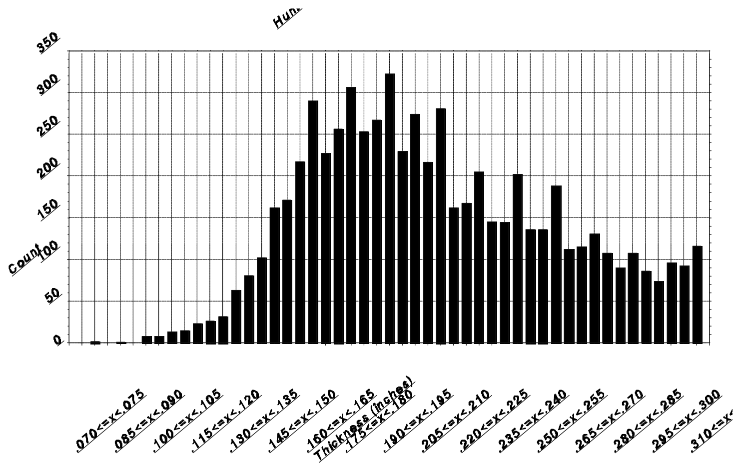

Figure 8. Region C Thickness Distribution in Tank 4 (Figure 7)

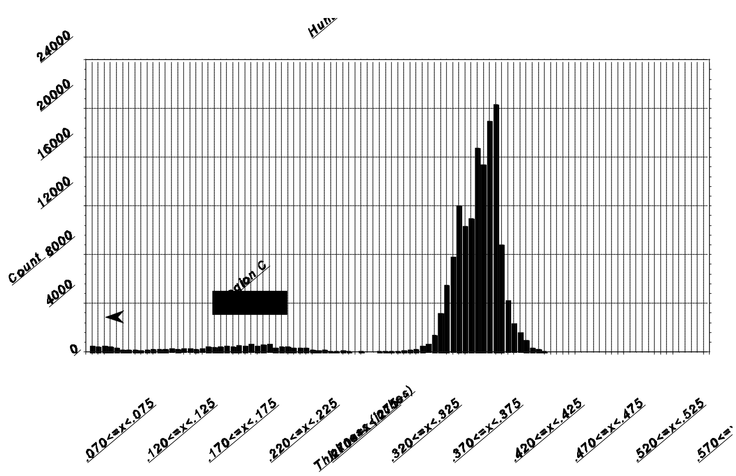

Figure 9. Tank 5 Thickness Distribution

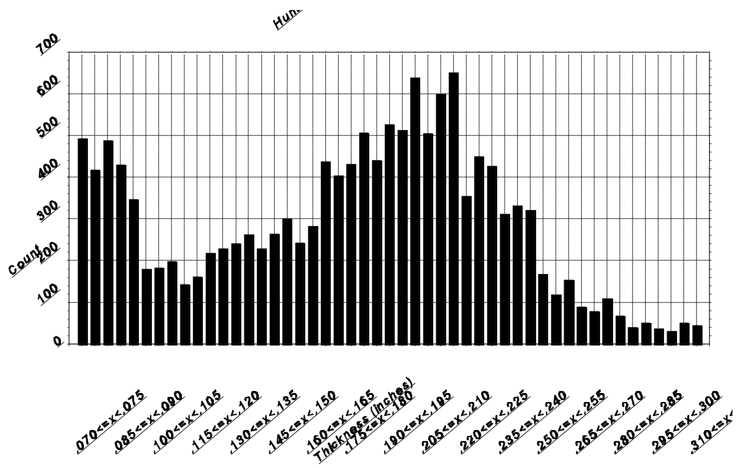

Figure 10. Region C Thickness Distribution Tank 5, (Figure 9)

CONCLUSION

A remote robotic UST inspection and condition assessment system has been both validated and demonstrated at two separate sites, on a total of four tanks. Virtually all the capabilities of the system were verified and documented. In terms of the rate of wall thickness data acquisition, Fury is at least a thousand times faster when compared to current methods. A major benefit is the ability to inspect a tank without requiring human entry. The results obtained from the Hunter AAF inspections are representative of how Fury can be used as a tool in order for owners to make better informed decisions about UST management. In addition, it will also allow tank owners to more cost effectively comply with federal, state and local requirements prior to the 1998 deadline and beyond.

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REFERENCES

[1] “Technical Standards And Corrective Action Requirements For Owners and Operators of Underground Storage Tanks (USTs)”

[2] James H. Pim, P.E., and, John M. Searling, “Tank Corrosion Study (Final Report),” Suffolk County Department of Health Services, November 1988, for the USEPA Office of Underground Storage Tanks.
[3] “Causes of Release from UST Systems,” USEPA Report UST32A/B, 30 September 1987. Specifically, p. 2 and p. 7.
[4] ASTM Standard: Guide for Three Methods of Assessing Buried Steel tanks Prior to Upgrading with Cathodic Protection (revised from ES 40)
[5] IT Corporation and Midwest Research Institute, “Quality Assurance Project Plan: Field Evaluation of UST Inspection Assessment Technologies,” October 1995
[6] ASTM G46-94 Standard Guide for Examination and Evaluation of Pitting Corrosion